

WD # 415965



HIGH POWER ULTRASONIC TRANSDUCERS

Applicant: Thomas T. Hansen et al.

Serial No.: 09/577,805

1. (Amended) A high power ultrasonic transducer comprising a housing having a predetermined geometry, means carried by the housing for providing power in excess of three kilowatts including a transducer having one or more active elements made from a giant magnetostrictive material and means for producing an electromagnetic field which extends through at least a portion of the one or more active elements, the one or more active elements each changeable between a first shape when in the absence of the electromagnetic field and a second shape when in the presence of the electromagnetic field, means for providing an electrical signal to the means for producing an electromagnetic field and an acoustic element connected to the transducer for channeling ultrasonic energy to perform work.
2. The ultrasonic transducer of Claim 1 wherein there is one cylindrically-shaped active element and wherein the means for producing an electromagnetic field is a coil made from conductive material concentrically disposed about the active element.
3. The ultrasonic transducer of Claim 2 further comprising magnetic means for biasing the active element.
4. The ultrasonic transducer of Claim 3 wherein the magnetic means includes tubular magnetic means concentrically disposed about the cylindrical element, the tubular magnetic means having first and second opposite end portions and a central portion between the first and second end portions, the first and second end portions having a radial thickness and the central portion having a radial thickness which is less than the radial thickness of the end portions for producing a substantially uniform bias over the length of the cylindrical element.

the first and
the central
portions for

-
5. The ultrasonic transducer of Claim 4 wherein the first and second end portions having an inner diameter and the central portion has an inner diameter which is less than the inner diameter of the end portions.
6. The ultrasonic transducer of Claim 5 wherein the first and second end portions are first and second annular members and wherein the central portion is a third annular member disposed between the first and second annular members.
7. The ultrasonic transducer of Claim 2 wherein the cylindrical element has first and second opposite ends, first and second flux return elements carried by the housing adjacent the first and second ends of the cylindrical element for capturing magnetic flux through the cylindrical element.
8. (Amended) The ultrasonic transducer of Claim 7 wherein the first and second flux return elements are first and second disk-like elements made from a material having an electrical resistivity of at least about 0.01 ohm-cm and a magnetic saturation flux density of at least about 8,000 gauss.
10. The ultrasonic transducer of Claim 1 further comprising magnetic means for biasing the active element.
11. The ultrasonic transducer of Claim 1 wherein the acoustic element is mounted on the transducer and is made from a material having a quarter resonant wavelength, the acoustic element having a length equal to the quarter resonant wavelength of the material.
12. The ultrasonic transducer of Claim 1 wherein the acoustic element is made from an acoustic metal.

-
13. The ultrasonic transducer of Claim 12 wherein the acoustic element is made from a magnesium alloy.
14. (Amended) The ultrasonic transducer of Claim 1 for use with a cooling fluid, the transducer including a passageway about the transducer adapted to receive the cooling fluid, the passageway formed from a material which is an electrical insulator.
16. (Amended) The ultrasonic transducer of Claim 14 wherein the material has a thermal conductivity greater than about one (1) W/m-K.
17. (Amended) The ultrasonic transducer of Claim 14 wherein the passageway is formed from hot pressed boron nitride.
18. (Amended) The ultrasonic transducer of Claim 14 wherein the passageway is a helical passageway within the transducer.
19. (Amended) A high power ultrasonic transducer comprising a housing having a predetermined geometry, means carried by the housing for providing power in excess of three kilowatts including a transducer having a cylindrical actuation element made from a giant magnetostrictive material and a coil made from electrically conductive wire concentrically disposed about the cylindrical element for producing an electromagnetic field that extends through at least a portion of the cylindrical element, the cylindrical element changeable between a first shape when in the absence of the magnetic field and a second shape when in the presence of the magnetic field, means for supplying an electrical signal to the coil and an acoustic element connected to the transducer for vibrating at an ultrasonic frequency in response to the transducer for performing work.

20. (Amended) The ultrasonic transducer of Claim 19 further comprising means for actively cooling the transducer which includes a fluid-carrying passageway which extends about the transducer, wherein the passageway is an electrical insulator.

22. (Amended) The ultrasonic transducer of Claim 20 wherein the fluid-carrying helical] passageway is a helical passageway that extends through the cylindrical element.

24. (Amended) A high power ultrasonic transducer comprising a housing having a predetermined geometry, a transducer having a rod-like element made from a giant magnetostrictive material and a coil made from electrically conductive wire concentrically disposed about the rod-like element changeable between a first shape when in the absence of the magnetic field and a second shape when in the presence of the magnetic field, tubular magnetic means concentrically disposed about the coil for biasing the rod-like element and having first and second opposite end portions and a central portion between the first and second end portions, the first and second end portions having a radial thickness which is less than the radial thickness of the end portions, means for supplying a sinusoidal electrical signal to the coil, means for actively cooling the transducer which includes an electrical insulator for forming a fluid-carrying passageway which extends about the transducer, the rod-like element having first and second ends, first and second flux return means carried by the housing adjacent the first and second ends of the rod-like element for capturing magnetic flux through the rod-like element and an acoustic element connected to the transducer for vibrating at an ultrasonic frequency in response to the transducer for producing useable work wherein the first and second flux return means are adjacent to the first and second end portions of the tubular magnetic means are made from a material having an electrical resistivity of at least about 0.01 ohm-cm and a magnetic saturation flux density of at least about 8,000 gauss.

25. The ultrasonic transducer of Claim 24 wherein the first and second flux return means are adjacent the first and second end portions of the tubular magnetic means.

27. (Amended) The ultrasonic transducer of Claim 24 wherein the electrical insulator for forming the fluid-carrying passageway is a ceramic material .

28. (Amended) The ultrasonic transducer of Claim 27 wherein the ceramic material is selected from the group consisting of boron nitride, aluminum nitride, alumina, silicon carbide, boron carbide, silicon nitride, pyrolitic boron nitride, beryllia, silicon, and any combination thereof.

29. (Amended) A high power magnetostrictive ultrasonic actuator comprising an active element made from a giant magnetostrictive material having first and second ends, the giant magnetostrictive element changeable from a first shape to a second shape in the presence of a magnetic field, means for producing a magnetic field which extends through at least a portion of the active element and first and second flux return elements adjacent to the first and second ends of the giant magnetostrictive element for capturing magnetic flux produced by said means and directing the magnetic flux through the giant magnetostrictive element.

30. (Amended) An actuator as in Claim 29 wherein the means for producing a magnetic field includes a coil concentrically disposed about the giant magnetostrictive element.

31. (Amended) An actuator as in Claim 29 further comprising a permanent magnet concentrically disposed about the giant magnetostrictive element for providing a Dc magnetic bias to the giant magnetostrictive element, the permanent magnet having first and second ends, the first and second flux return elements adjacent the first and second ends of the permanent magnet for capturing magnetic flux produced by the permanent magnet and directing said flux through the giant magnetostrictive element.

32. An ultrasonic transducer comprising:

a plurality of sub-motors, each containing a prestress bolt located proximate to an active element, wherein the sub-motors are designed to operate simultaneously;

a refrigeration system connected to the transducer, the refrigeration system utilizing a phase change cooling medium designed to cool each active element; and

a master wave-guide connected to the plurality of sub-motors, the master wave-guide designed to be reactive to ultrasonic energy produced by the plurality of sub-motors, wherein the master wave-guide channels the ultrasonic energy to perform work on a continuous basis.

33. The ultrasonic transducer of claim 32 wherein the master wave-guide is a composite master wave-guide comprised of a mode stabilizer and an output amplifier, further wherein the mode stabilizer is made from a material having a speed of sound in excess of 6000 meters per second.

34. The ultrasonic transducer of claim 33 wherein the ultrasonic transducer is capable of receiving up to 30 kW of power and outputting frequency in excess of 18 kHz on a continuous basis.

35. The ultrasonic transducer of claim 33 wherein the mode stabilizer and output amplifier each comprise a single one-half wavelength wave-guide, further wherein the transducer can produce a one-full wavelength standing wave in one complete cycle.

36. The ultrasonic transducer of claim 35 wherein each active element is a one-half wavelength drive rod made from a smart material.

37. The ultrasonic transducer of claim 36 wherein the smart material is selected from the group consisting of piezoelectrics, ferroelectrics, piezoceramics and magnetostrictive materials.

-
38. The ultrasonic transducer of claim 37 wherein the mode stabilizer is made from aluminum-beryllium, beryllium or a metal matrix alloy and the output amplifier is made from titanium or a titanium alloy.
39. The ultrasonic transducer of claim 32 wherein the refrigeration system comprises a single loop cooling system or a double loop cooling system.
40. The ultrasonic transducer of claim 39 wherein the phase change cooling medium is a low-boiling hydrocarbon, ammonia or water.
41. The ultrasonic transducer of claim 32 further comprising:
a drive coil surrounding the plurality of sub-motors to provide an electromagnetic field;
and
a magnetic circuit surrounding the drive coil, the magnetic circuit designed to bias the active elements.
42. The ultrasonic transducer of claim 41 wherein the drive coil has foil windings with a packing factor greater than about 85%.
43. The ultrasonic transducer of claim 41 wherein the magnetic circuit comprises:
each active element;
flux concentrators surrounding each active element;
two magnetic rings surrounding all active elements; and
a plurality of cylindrical magnetic pieces located between the two magnetic rings wherein the magnetic circuit is activated when a dc current is provided.
44. The ultrasonic transducer of claim 43 wherein each active element is comprised of a split active element having two sections.

-
45. The ultrasonic transducer of claim 44 wherein each sub-motor further comprises:
- a mode containment disk located between the two sections of the split active element, the mode containment disk designed to increase cooling of the split active element;
 - a sub-motor wave-guide contiguous with the prestress bolt;
 - a gap located between the split active element and the prestress bolt, the gap designed to hold ceramic powder;
 - one or more sub-motor flux concentrators located next to the split active element;
 - a preload disk located adjacent to one of the one or more sub-motor flux concentrators;
- and
- a preload nut located adjacent to the preload disk.
46. The ultrasonic transducer of claim 45 wherein the preload nut, one flux concentrator and the preload disk comprise a reaction mass against which the split active element can push.
47. The ultrasonic transducer of claim 45 wherein the ceramic powder in the gap is boron nitride.
48. The ultrasonic transducer of claim 45 wherein the mode containment disk is a ceramic disk.
49. The ultrasonic transducer of claim 45 comprising six sub-motors arranged in a ring pattern about a longitudinal axis of the transducer.
50. The ultrasonic transducer of claim 39 wherein the single loop cooling system comprises:
- a heat load source designed to heat the phase change cooling medium, wherein the phase change cooling medium is converted from a fluid-vapor mixture to a superheated vapor;
 - a compressor located downstream from the heat load source, the compressor designed to keep the superheated vapor under pressure;

a condenser located adjacent to the compressor, the condenser designed to allow the superheated vapor to release heat to produce a sub-cooled fluid; and

an expansion device designed to throttle the sub-cooled fluid prior to entering the transducer.

51. The ultrasonic transducer of claim 45 wherein the wave-guide has a tip, further wherein the wave-guide tip can be displaced about 60 micrometers or more peak-to-peak.

52. The ultrasonic transducer of claim 45 wherein the transducer can be used in sonochemical processes.

53. A method for channeling ultrasonic energy to perform work comprising:
providing a transducer having a plurality of sub-motors, each sub-motor containing a prestress bolt located proximate to an active element;
operating the sub-motors simultaneously;
flowing a phase change cooling medium through the transducer and through a refrigeration system connected to the transducer; and
placing a master wave-guide in a direct load path of the plurality of sub-motors, wherein the master wave-guide is reactive to ultrasonic energy provided by the plurality of sub-motors.

54. The method of claim 53 further comprising activating the transducer by providing power to a magnetic circuit surrounding the sub-motors, wherein the ultrasonic energy from the sub-motors is channeled to produce work on a continuous basis.

55. The method of claim 53 further comprising exposing each active element to an electromagnetic field.

56. The method of claim 53 wherein high power work is provided in excess of ten (10) kW.

57. The method of claim 55 wherein the electromagnetic field is provided by a coil made from a conductive material, the coil concentrically disposed about the plurality of sub-motors.

58. The method of claim 57 further comprising providing a dc current to bias the active element.

59. The method of claim 57 wherein two magnetic rings surround the coil, further wherein ferromagnetic pieces are arranged between the two magnetic rings for reducing system heating requirements.

60. The method of claim 53 wherein each active element is a one-half wavelength drive rod made from a smart material.

61. The method of claim 60 wherein the smart material is selected from the group consisting of piezoelectrics, ferroelectrics, piezoceramics and magnetostrictive materials.

62. The method of claim 53 wherein the master wave-guide is a composite master wave-guide comprised of a mode stabilizer and an output amplifier, further wherein the mode stabilizer is made from a material having a speed of sound in excess of 6000 meters per second.

63. The method of claim 53 further comprising:
splitting the active element into two sections to form a $1/2$ wavelength drive rod;
guiding magnetic field intensity through the split active element with one or more flux concentrators;
cooling an inner diameter of each split active element with a silicon nitride or alumina disk; and

adding ceramic powder to a gap between the prestress bolt and the split active element to increase cooling of the split active element.

64. The method of claim 63 wherein power generating capability of each drive rod is enhanced by about four times with the one or more flux concentrators.

65. The method of claim 63 further comprising:

allowing the flowing phase change cooling medium to contact a seal plate located in the transducer and splatter radially into prestress bolt intake openings, wherein the cooling medium is a fluid prior to contacting the seal plate and a fluid-vapor mixture after contacting the seal plate;

venting the fluid-vapor mixture through an exhaust port in the transducer, the mixture first exiting each prestress bolt through prestress bolt outlet openings; and

in the refrigeration system, heating the fluid-vapor mixture prior to flowing it through a compressor to produce a superheated vapor.

66. The ultrasonic transducer of claim 37 wherein the magnetostrictive material is TERFENOL or TERFENOL-D.

67. The ultrasonic transducer of claim 66 wherein the TERFENOL or TERFENOL-D is laminated.

68. The ultrasonic transducer of claim 50 wherein the double loop cooling system further comprises a heat exchanger through which the cooling medium can flow to transfer heat.

69. The ultrasonic transducer of claim 50 wherein the heat load source is variable or constant.

70. The ultrasonic transducer of claim 69 wherein the expansion device is an expansion valve or a thermal expansion valve.

71. The ultrasonic transducer of claim 40 wherein the phase change medium is a refrigerant selected from the group consisting of R-134a, R-123a, R-124, R-22/152a/124, R600, R600a, HC-601, HC-601a, R-717, R-744, RC270, PFC-C318, R-E134, dimethyl ether and R-E245fa1.

72. The ultrasonic transducer of claim 50 wherein each prestress bolt has prestress bolt inlet openings through which a cooling medium fluid can enter and prestress bolt outlet openings through which a cooling medium fluid-vapor mixture can exit.

73. (Amended) The ultrasonic transducer of claim 32 wherein the refrigeration system is a chiller system.

74. The method of claim 60 wherein the magnetostrictive material is TERFENOL or TERFENOL-D.